REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
31 August 2016	Briefing Charts	31 August 2016 – 03 October 2016

4. TITLE AND SUBTITLE
Modeling Fluid-Structure Interaction in ANSYS Workbench

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Sam Dupas

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
Q0XZ

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/RQRM
4 Draco Drive
Edwards AFB, CA 93524-7160

8. PERFORMING ORGANIZATION REPORT NO.

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Research Laboratory (AFMC)
AFRL/RQR
5 Pollux Drive
Edwards AFB, CA 93524-7048

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFRL-RQ-ED-VG-2016-281

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited. The U.S. Government is joint author of the work and has the right to use, modify, reproduce, release, perform, display, or disclose the work.

13. SUPPLEMENTARY NOTES
For presentation at Intern Symposium IV (Internal); AFRL RQ-West, Edwards AFB, CA (31 August 2016)
PA Case Number: #16480; Clearance Date: 10/3/2016
Prepared in collaboration with Sierra Lobo

14. ABSTRACT
Viewgraph/Briefing Charts

15. SUBJECT TERMS
N/A

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					G. Trapp
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	SAR	18	**19b. TELEPHONE NO** *(include area code)*
Unclassified	**Unclassified**	**Unclassified**			N/A

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18

Air Force Research Laboratory

Integrity ★ Service ★ Excellence

Modeling Fluid-Structure Interaction in ANSYS Workbench

31 August 2016

Sam Dupas

AFRL/RQRM

Sierra Lobo, Inc.

AFRL

About Me

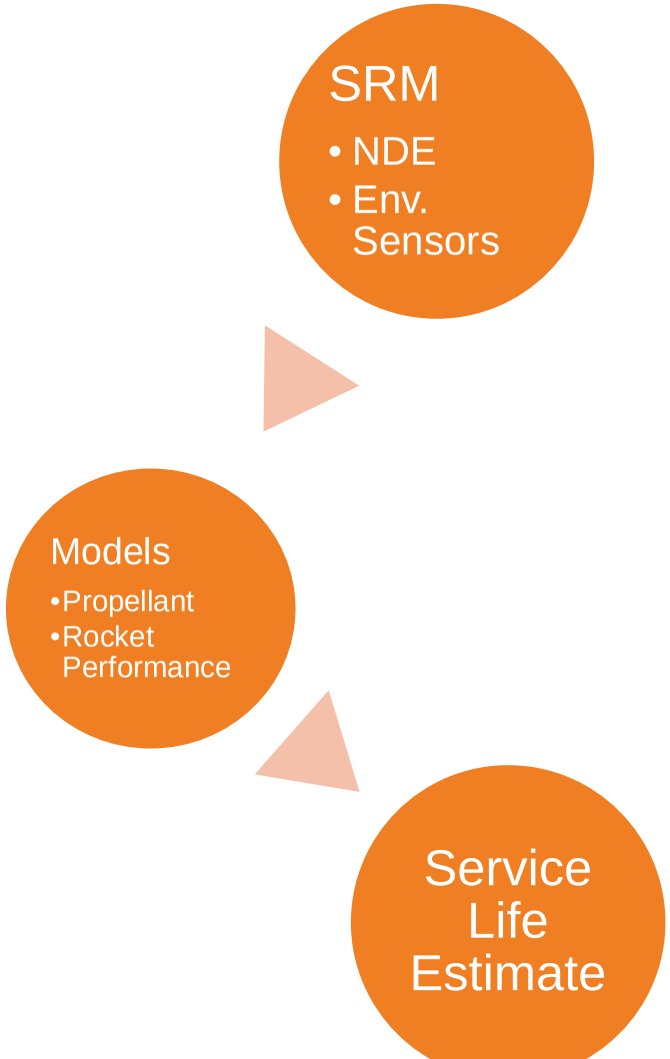
- **UCLA Aerospace Engineering ’17**
  - **Vishal Parikh Memorial Scholarship/AFRL Internship**
- **UCLA Rocket Project**
  - **Propulsion Chief Engineer ‘16-’17**
  - **Create a student-built hybrid rocket motor**
- **AFRL/RQRM Aging & Surveillance (A&S) Group**

Outline

- **Aging & Surveillance Overview**
- **Fluid-Structure Interaction (FSI)**
- **ANSYS Workbench Capabilities**
  - **Performing FSI Analysis in ANSYS Workbench**
    - 1-Way FSI
    - 2-Way FSI
  - **Automating FSI Analysis**
- **Conclusions & Future Work**
- **Acknowledgements**

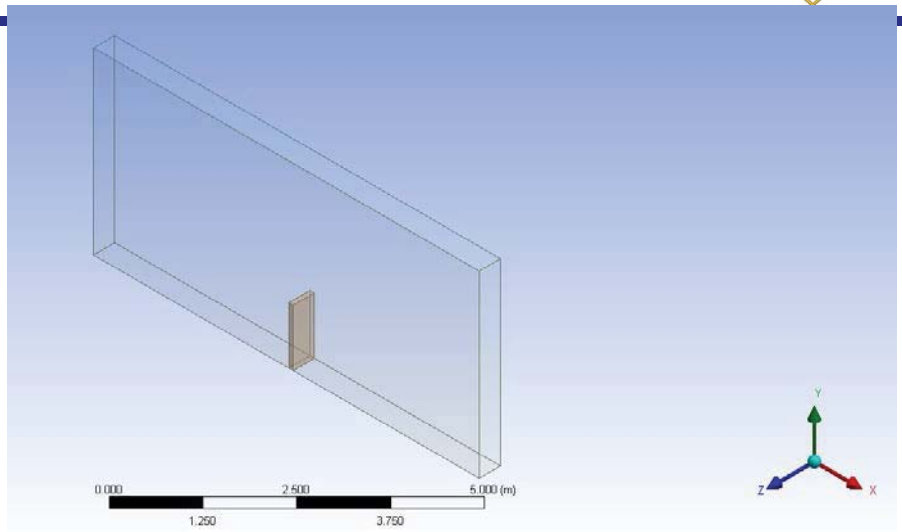
Aging & Surveillance Problem

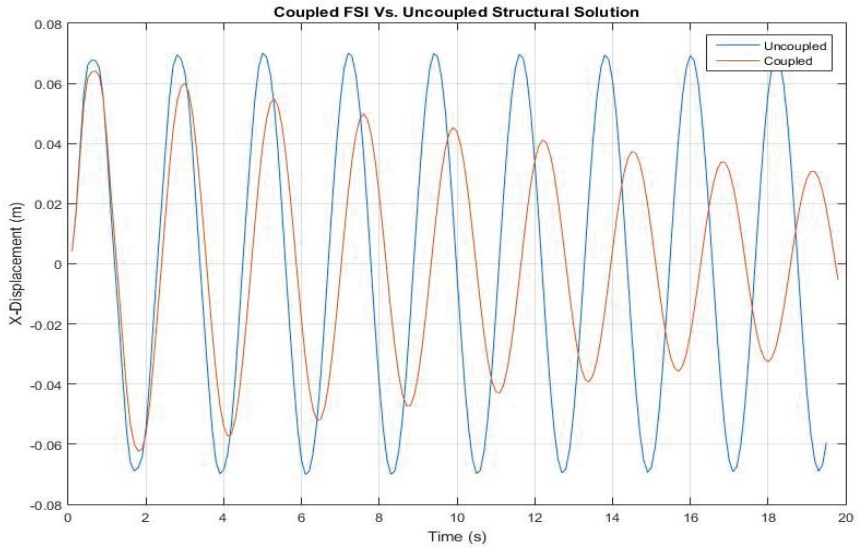
- **A&S attempts to figure out how an individual motor will behave after being stored for a period of time.**
- **Develop ways to gather data on individual motors.**
- **Model curing and aging of propellant, liner, and case, which all have changing mechanical properties.**
- **Model firing of motor to determine final behavior.**
  - **Goal was to use ANSYS Workbench to analyze fluid-structure interaction.**
- **Give a service life estimate for each individual motor, instead of a fleet wide SLE.**



Fluid-Structure Interaction

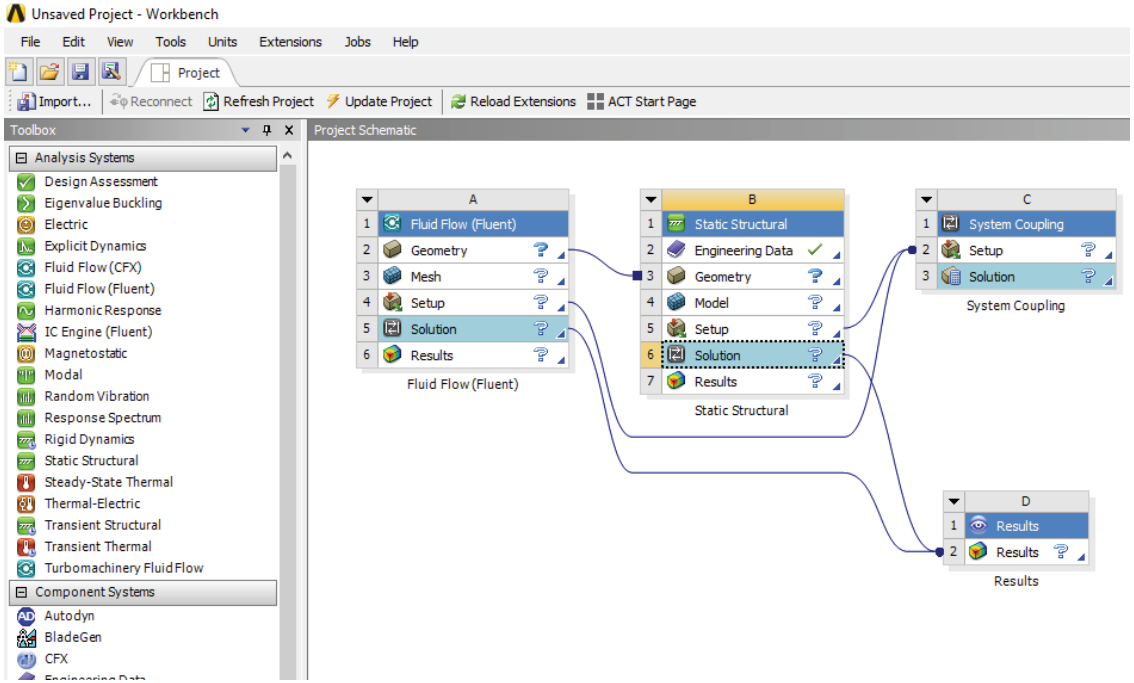
- **Fluid exerts loads on a solid structure, which then deforms.**
  - **Deformed solid changes the fluid flow characteristics.**
- **Situation can be modeled with various degrees of coupling between CFD and structural solvers.**
  - **CFD → Structural**
  - **CFD ↔ Structural**
- **In an A&S scenario, FSI is between combustion gas and remaining solid propellant.**
  - **Nonlinear viscoelasticity of materials makes simulation even more difficult.**





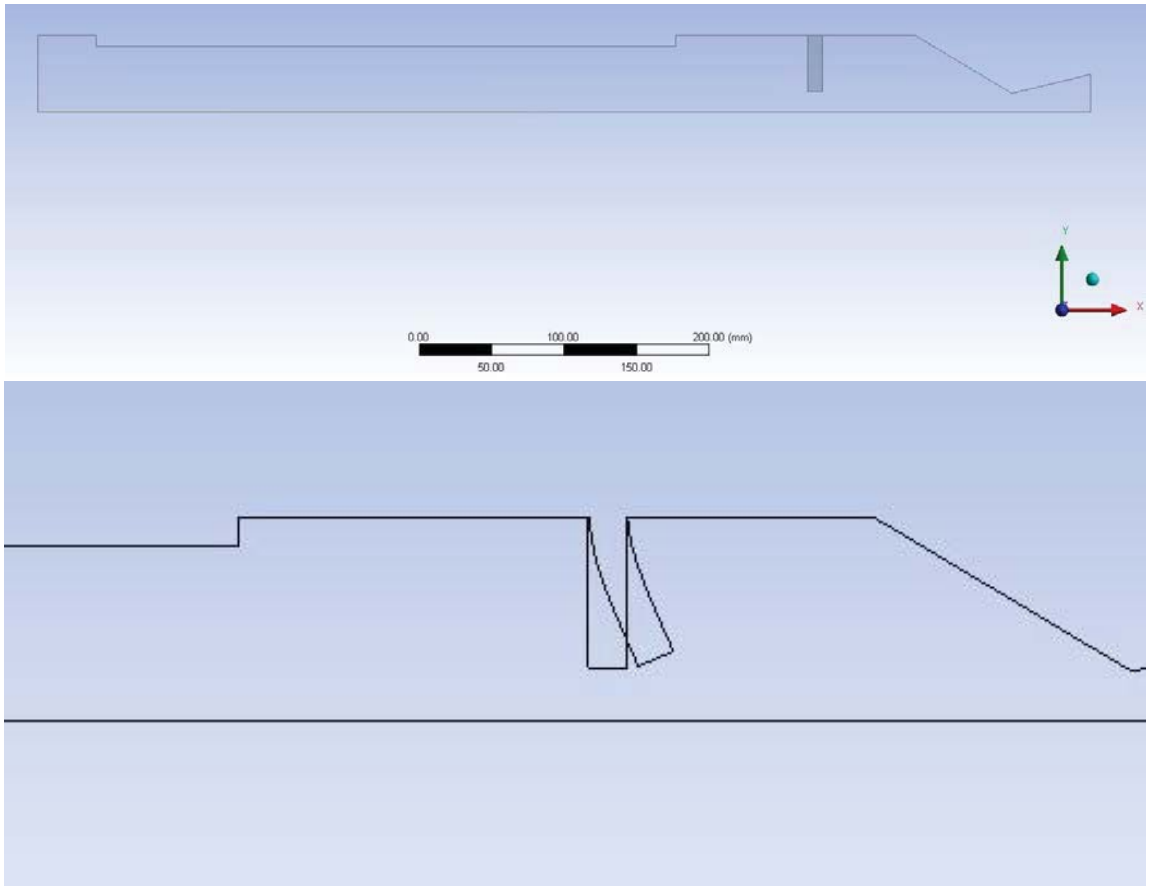
ANSYS Workbench

- **Multiphysics application containing multiple solvers.**
  - **Fluid, Structural, Dynamics, Thermal, Electromagnetic**
- **Steady state and transient simulations are possible.**
- **For FSI:**
  - **CFD Solver: Fluent**
  - **Structural Solver: ANSYS Mechanical**
- **Important limitation is that data transfers are only supported for 3D simulations.**

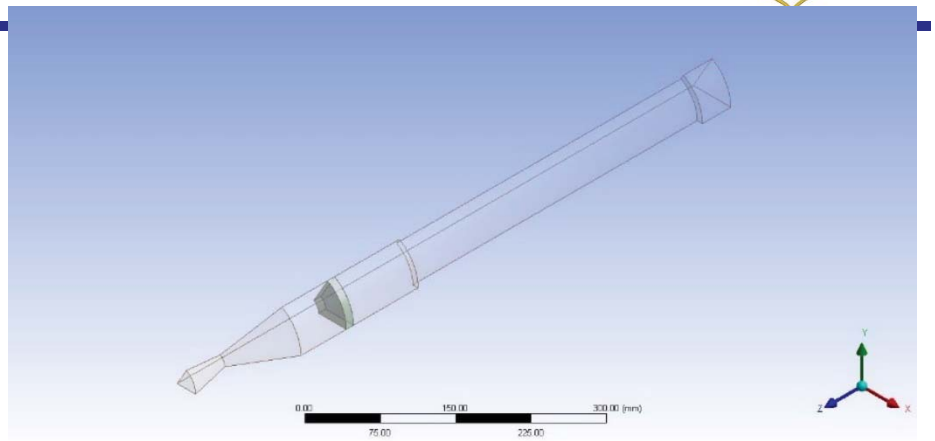


1-Way Steady State FSI

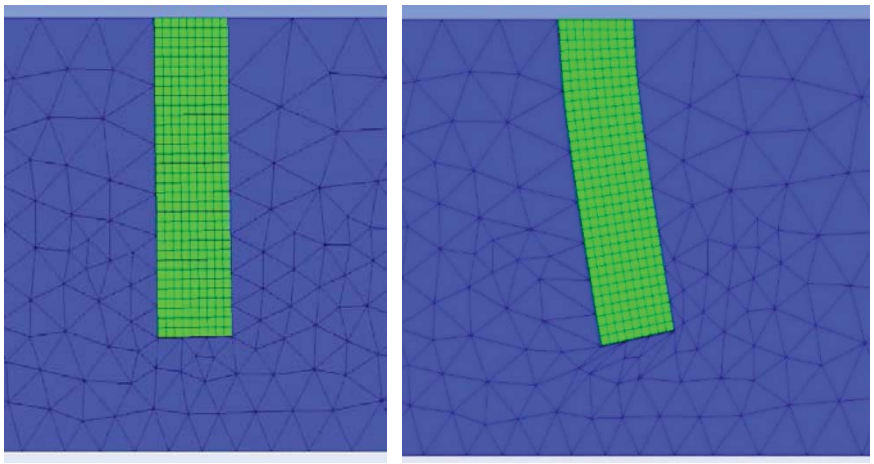
- 2D axisymmetric geometry.
- Fluent adjusts the inlet mass flux using a user defined function (UDF).
  - $\dot{m}/_A = \rho \times \dot{r} = \rho \times aP^n$
- Exporting and reimporting data allows workaround for 3D limitation.
- Solution is not coupled fully, lacks accuracy in situations with large deformations.
- 1-way data transfer does not support transient simulation.



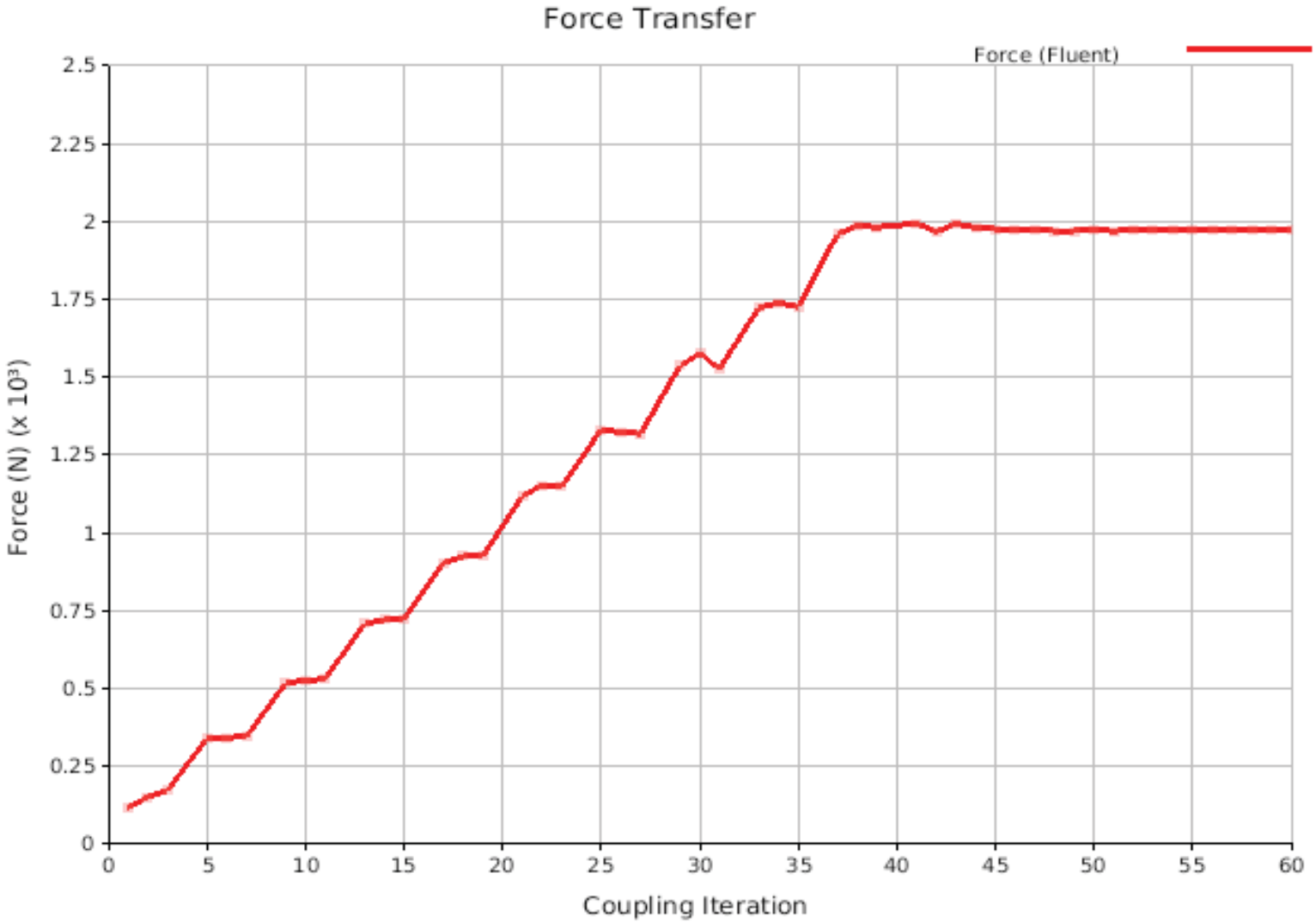
2-Way Steady State FSI



- The fluid mesh is deformed along with the structure.
- Revolved version of 2D geometry.
- Force ramping was used to prevent excessive overshoot in solid.
  - Not valid for transient simulations.
- Max deformation was about 66% of a 1-way solution on the same geometry.
  - 9.3 mm vs 5.9 mm

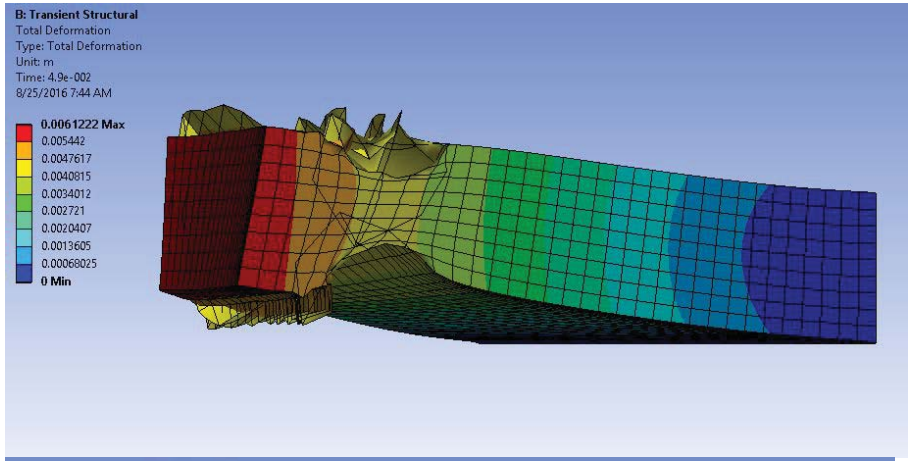


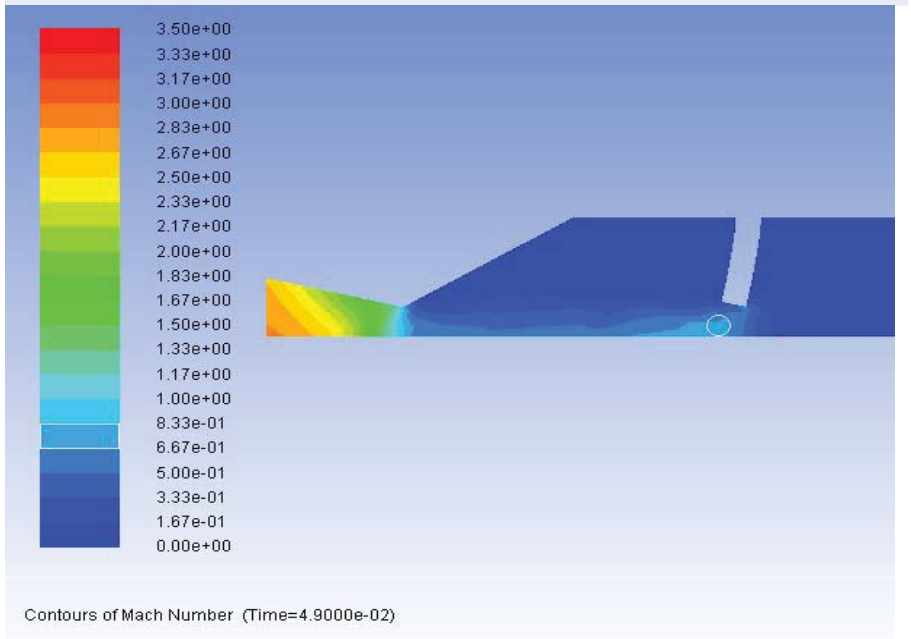
Steady-State FSI Force Ramping



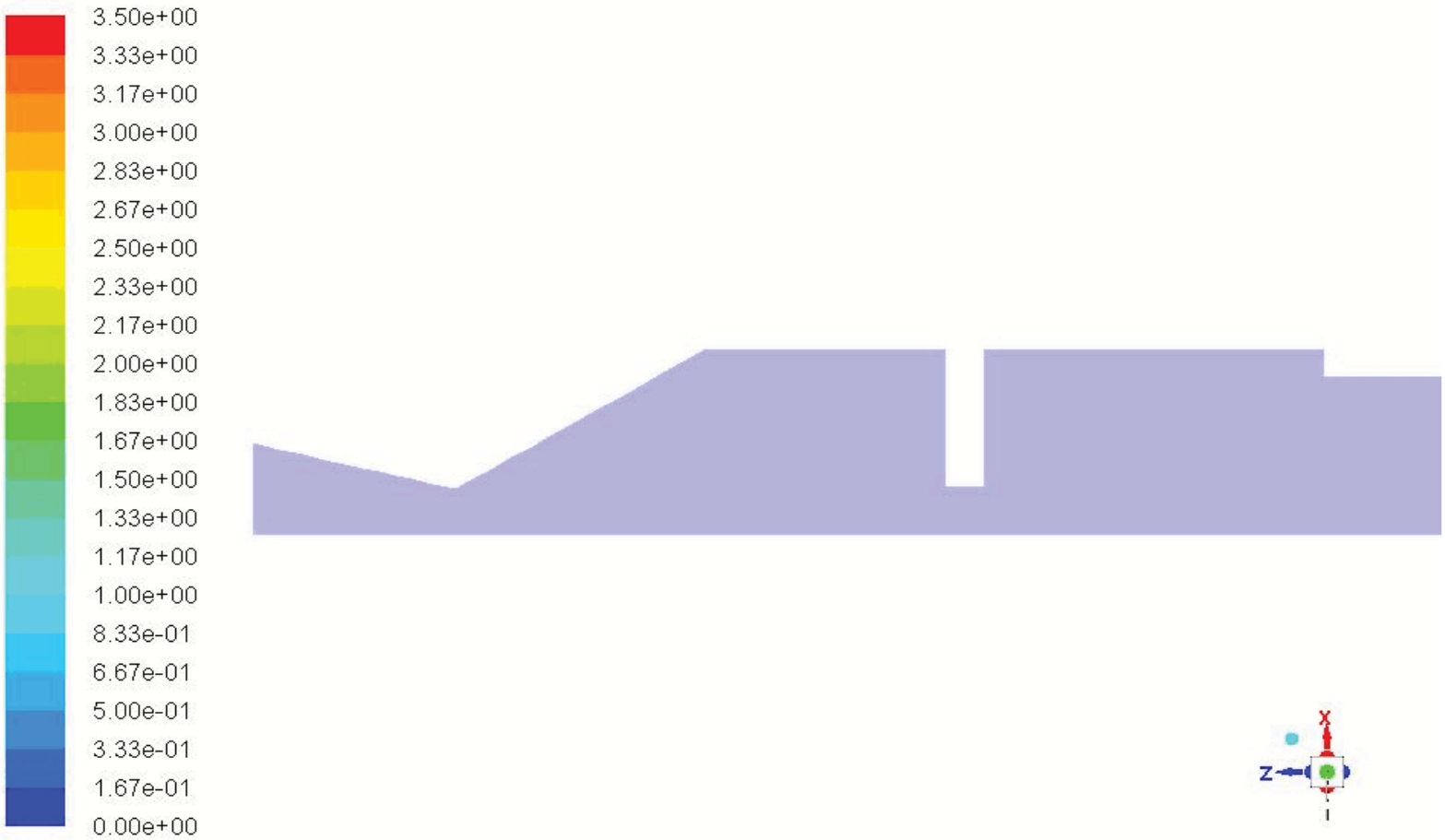
2-Way Transient FSI

- **Overshoot issues were solved by making the time step very small (0.001 seconds).**
  - **Once transients die down the time step can be increased.**
- **Becomes useful when UDF's simulating actual motor behavior are integrated into fluid solution.**
  - **Transient ignition, nozzle erosion, and more.**
- **The propellant flap initially chokes the flow, then the flow becomes subsonic.**
  - **Important to avoid bore choking when designing actual motors.**
- **Results approach the steady state solution before breaking down from excessive deformation.**

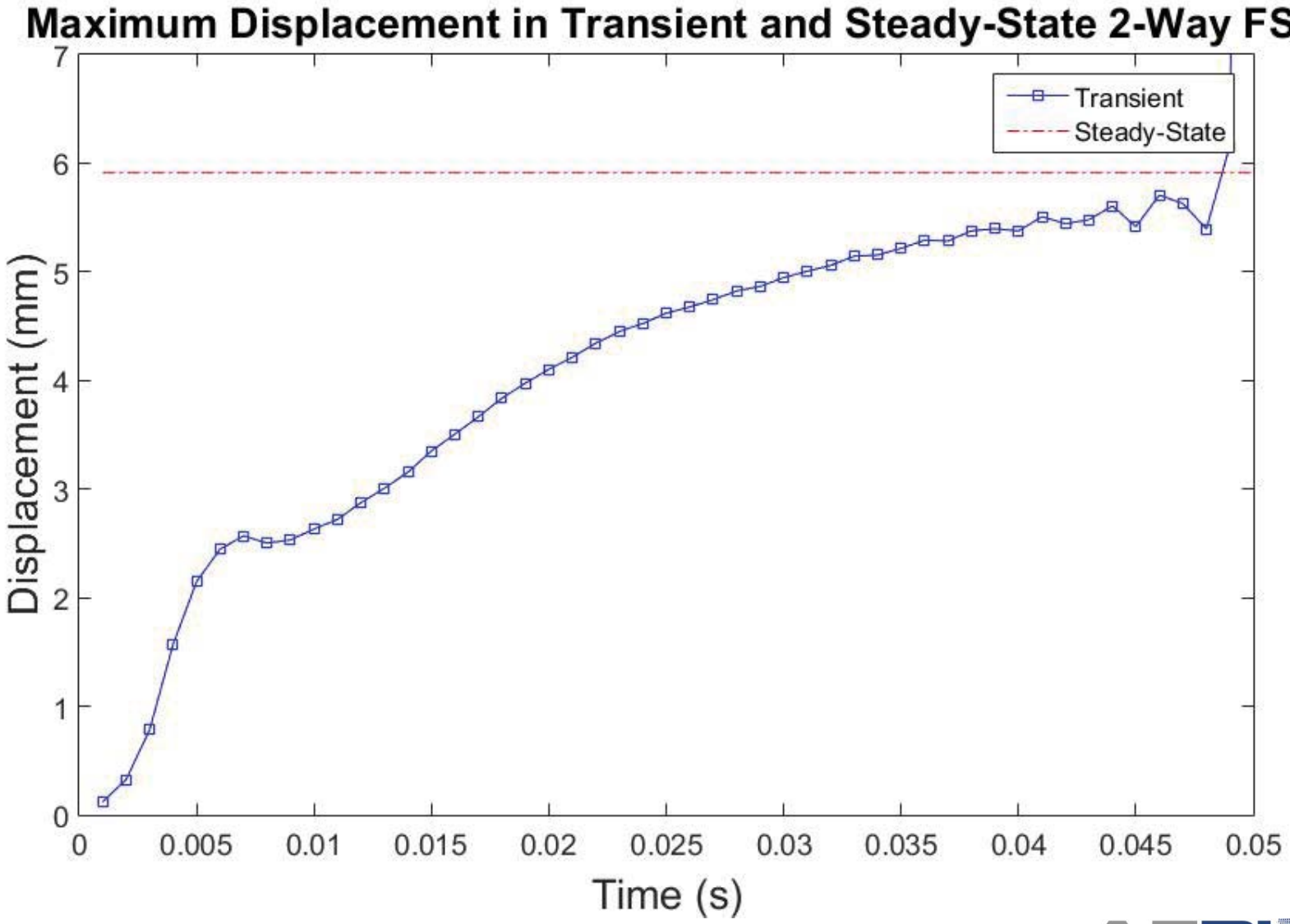




Transient FSI Results

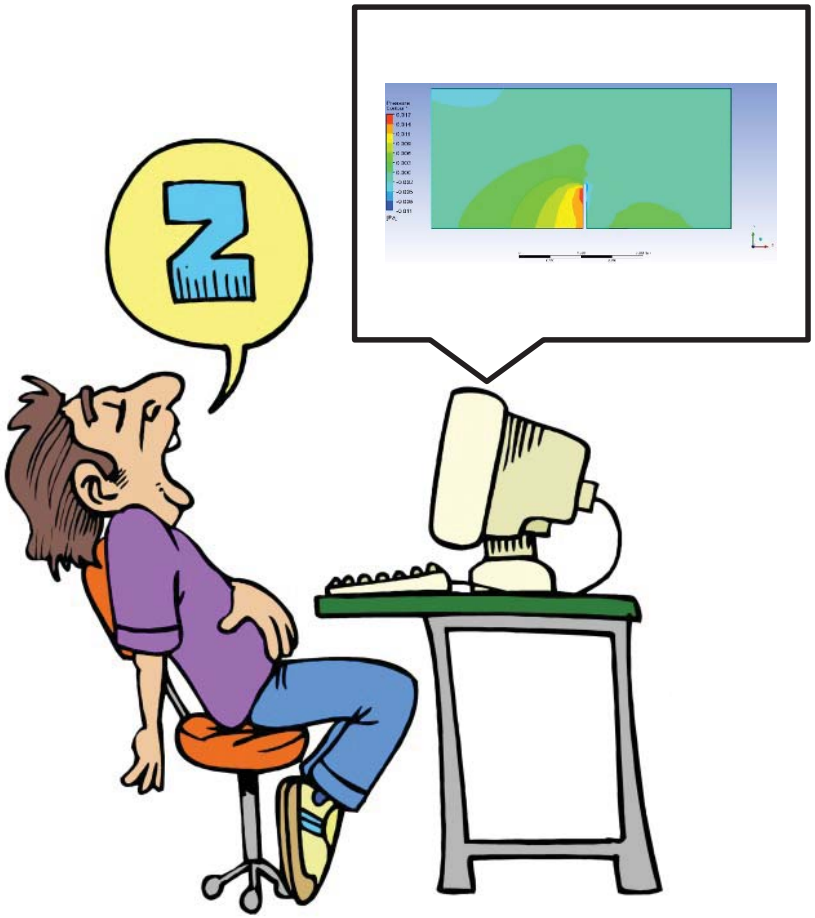


Transient FSI Results



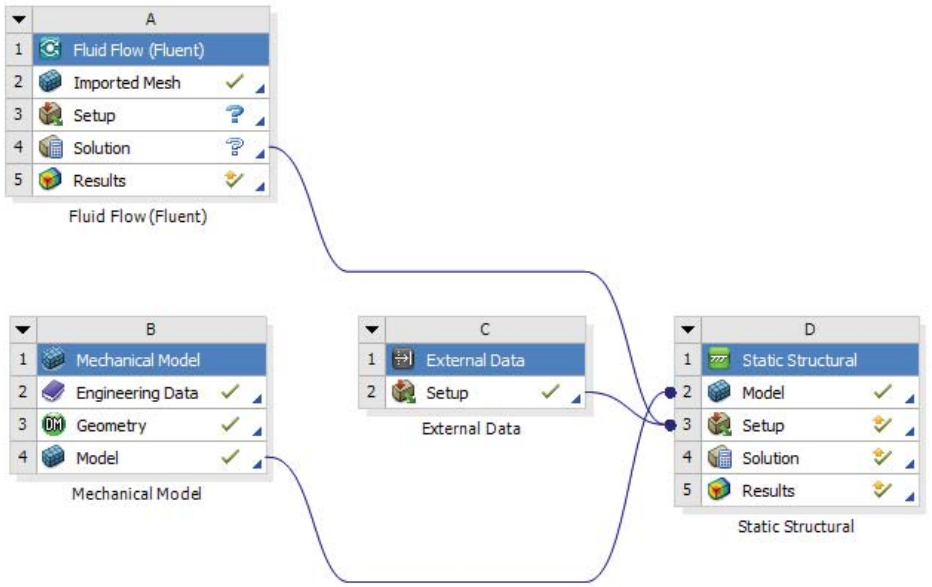
Automating ANSYS

- ANSYS can read Python scripts with instructions on how to perform an analysis.
- Fluent & Mechanical are "Data-Integrated" applications.
  - "Native" apps like System Coupling allow for direct scripting.
  - Data-integrated apps must be sent commands in their respective scripting languages.
- Most important feature (available in both Workbench and Fluent) is ability to record journals/scripts.
  - An analyst can perform the analysis once by hand, and ANSYS will create a Python file that will replicate those actions.



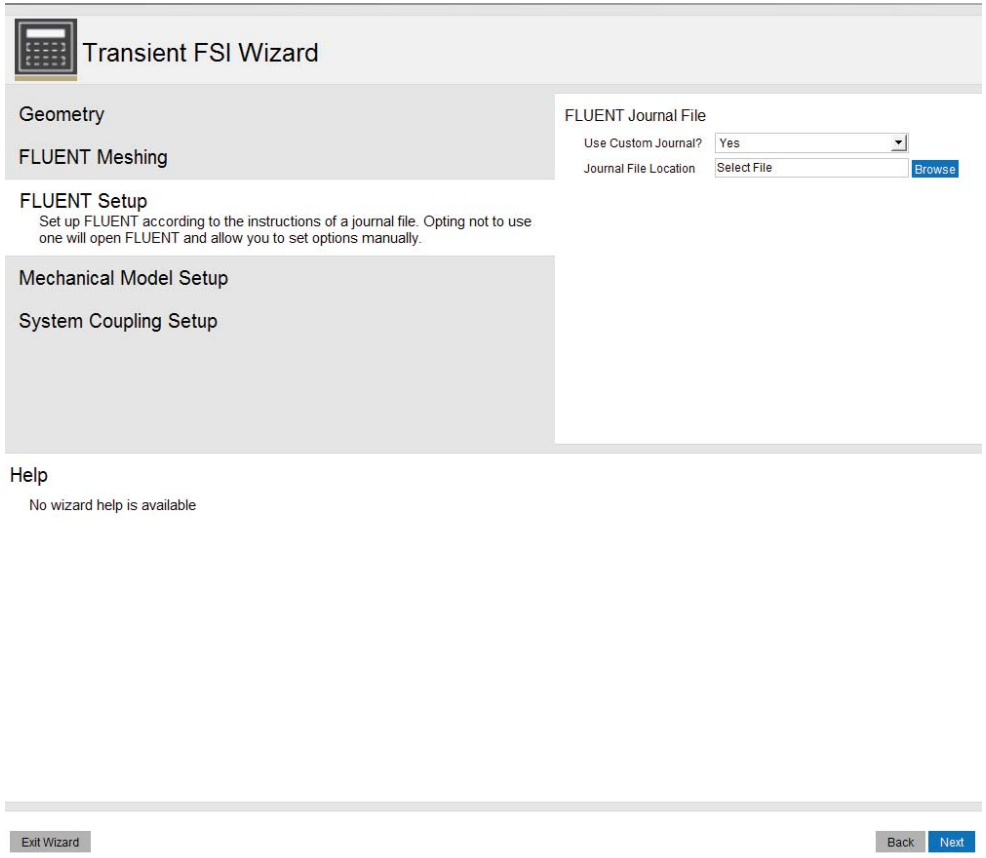
Automated 1-Way FSI

- **First attempt at automated analysis.**
- **Automatic Integrated New Technology Enabling Rapid Numerical Solutions (AutoINTERNs)**
- **Reads fluid and solid geometries, sets up and solves fluid problem, exports pressure to ANSYS Mechanical, and sets up structural analysis.**
- **Does not give a lot of flexibility in an analysis.**



Automated 2-Way FSI

- **ANSYS Guided Process**
  - **XML file combined with Python script.**
  - **HTML and images can also be added.**
- **Creates a step by step process that a user can follow.**
  - **Tasks like component/data linkage creation can still be automated.**
  - **Others like geometry creation/import can be left to the user.**
- **Once coded, files are "compiled" into a single extension file that can be loaded on any ANSYS installation.**



Conclusions & Future Work

Conclusions

- **ANSYS Workbench provides an intuitive framework for coupled analysis.**
  - **Many steps can be automated, which simplifies complicated or repeated analyses.**
  - **1-way coupling is generally not adequate for SRM simulation.**
- **ANSYS is exportable technology, which facilitates collaboration with foreign countries.**
- **Existing UDFs already work with Fluent, and need no modification.**
- **The requirement for 3D geometry increases computational load.**

Future Work

- **Improve long term stability of transient simulation.**
- **Integrate UDF's that better model transient motor behavior.**
- **Validate ANSYS Workbench solutions with test data.**
- **Add functionality to FSI Guided Process, such as images and help files.**

Acknowledgements

Thanks to:

Bill Harrigan and Geoffrey Trapp

Lt. Saif Ahmed

And everyone else at:

RQRM

Sierra Lobo, Inc.

AFRL

UCLA